SUBJECT: **SPIRE Low-pass filter calibration file description document**

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Draft 0.3	07 May 2009	Added the transfer functions and BODE plots of the LPF gain as derived from the LPF parameters. Included the transfer functions and BODE plots from the DCU design document for comparison. Added a note on an inconsistency in the DCU Design Document

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Glossary

CQM	Cryogenic Qualification Model
FM	Flight Model
LPF	Low-pass filter

1. INTRODUCTION

This document describes the purpose, contents, and the procedure for updating procedure the Low pass filter calibration product files used in the SPIRE Data Processing pipelines.

1.1 Structure of Document

Section 2 describes the background and the usage of the SPIRE Low-pass filter parameter calibration files. Section 3 introduces the general structure of the calibration files. The procedure that should be followed when populating the SPIRE Low-pass filter parameter calibration files is presented in Section 3.2. Finally, the contents of the current suite of SPIRE Low-pass filter parameter calibration files are given in Section 4.

1.2 Documents

1.2.1 Applicable Documents

Number	Document Name	Document Number	Issue
AD01	SPIRE Detector Control Unit Design Document	SPIRE-SAP-PRJ-001243	0.3
AD02	SPIRE Detector Control Unit Design Document	SPIRE-SAP-PRJ-001243	1.0
AD03	Calibration products for SPIRE Data Processing	SPIRE-RAL-DOC-002261	0.5
AD04	Delivery of Calibration Data From External Sites to RAL	http://www.herschel.be/twiki/bin/view/Spire/SpireIntDoc030700	

1.2.2 Reference Documents

RD01	Karki, James, "*Analysis of the Sallen-Key Architecture*", Application Report, Texas Instruments, rev. September 2002.

2. BACKGROUND

The readout chain for the SPIRE detectors, both the Photometer and the Spectrometer, contain a series of low pass filters (LPFs) [**AD01**, **AD02**]. The main purpose of these low pass filters is to attenuate unwanted, out-of-band frequencies thereby reducing contamination of the measured detector signals. A side effect of this filtering is to introduce a phase delay to the recorded signals. This phase delay, if left uncorrected, can have deleterious effects on the end products that are produced by pipeline processing. A set of calibration products have been defined, the contents of which will allow dedicated pipeline processing modules to characterize and correct for this induced phase delay.

2.1 Low-pass filters

2.1.1 Nominal Low-pass filters

An example of the low pass filter chain for the SPIRE Spectrometer detectors is shown in Figure 2.1 [**AD01**].

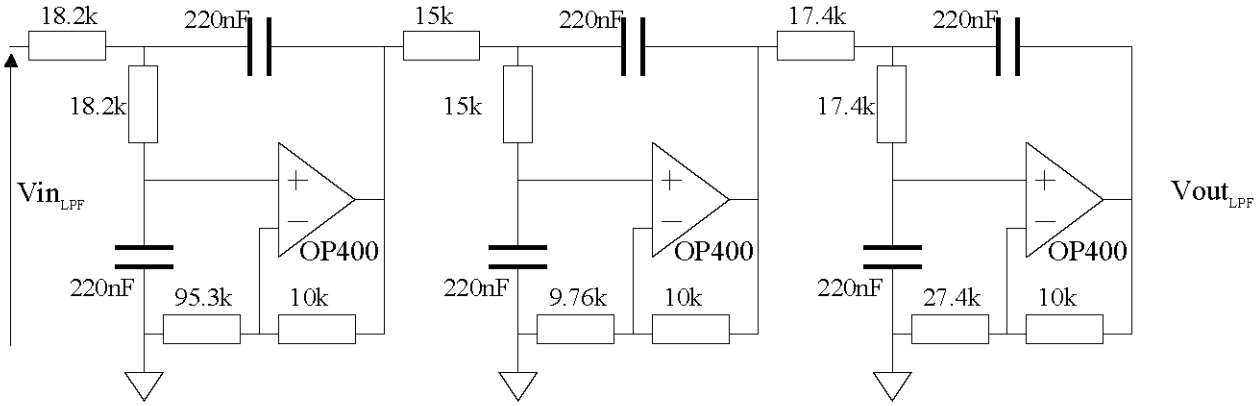

Figure 2.1: SPIRE Spectrometer LPF circuit [AD01]

Closer inspection of the LPF circuit in Figure 2.1 reveals it to be a chain of three Sallen-key LPFs [**RD01**].

The general Sallen-key LPF circuit is shown in Figure 2.2.

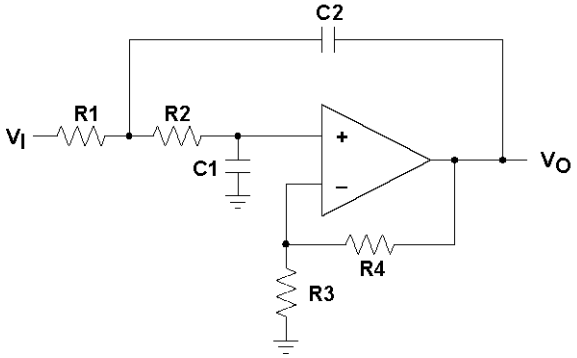

Figure 2.2: Low-Pass Sallen-Key Circuit [RD01]

The transfer function for the Sallen-key LPF shown is given as in Equation 2.1:

$$H(s) = \left[\frac{K}{s^2(R_1R_2C_1C_2) + s(R_1C_1 + R_2C_1 + R_1C_2(1-K)) + 1} \right]$$

Equation 2.1: Sallen-key LPF transfer function [RD01]

where $s=j\omega=j2\pi f$ and $K = 1+R_4/R_3$.

The overall transfer function for the filter shown in Figure 2.1, *H(s)*, is therefore given by Equation 2.2:

$$H(s) = H_1(s)H_2(s)H_3(s)$$

Equation 2.2: Overall transfer function for a series of Sallen-key LPFs

The magnitude and frequency response of the LPF chain are in turn given by Equation 2.3 and Equation 2.4, respectively.

$$|H(s)| = |H_1(s)H_2(s)H_3(s)|$$

Equation 2.3: Magnitude response for a series of Sallen-key LPFs

$$\phi(s) = Tan^{-1}\left[\frac{\mathrm{Im}(H_1(s)H_2(s)H_3(s))}{\mathrm{Re}(H_1(s)H_2(s)H_3(s))} \right]$$

Equation 2.4: Frequency response for a series of Sallen-key LPFs

It is therefore possible to derive both the magnitude and frequency response of the detector LPFs starting with just the individual resistor and capacitor components of the filters. Based on this, a set of calibration files were designated to contain these resistor and capacitor values for each of the Photometer and Spectrometer LPFs. The appropriate data reduction modules can then ingest the information from these calibration files and characterize the effect that these filters have on the recorded detector data. These effects may then be corrected using the most suitable de-filtering algorithm.

2.1.2 Non-nominal Low-pass filters

An example of the low pass filter chain for the SPIRE Spectrometer detectors is shown in Figure 2.1 [**AD01**].

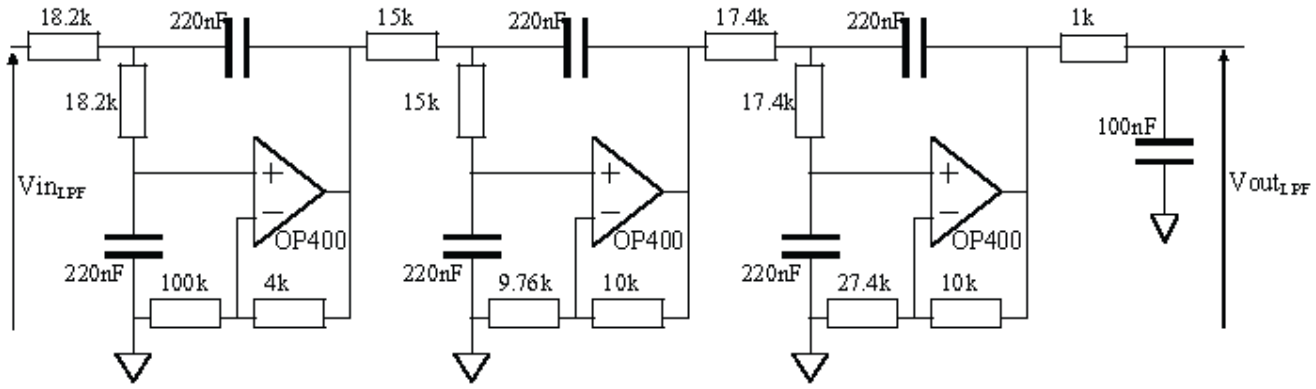

Figure 2.3: SPIRE Spectrometer LPF circuit [AD02]

As can be seen in Figure 2.3, the last filter in the chain shown does not follow the Sallen-key design. Rather, it is a simple RC low-pass filter. The transfer function for such a filter is given by

$$H_{RC}(s) = \frac{1}{1+sRC}$$

Equation 2.5: Simple RC LPF transfer function

The magnitude and frequency response of the LPF chain for this case are given by Equation 2.6 and Equation 2.7, respectively.

$$|H(s)| = |H_1(s)H_2(s)H_3(s)H_{RC}(s)|$$

Equation 2.6: Magnitude response for a series of Sallen-key LPFs with an additional RC LPF

$$\phi(s) = Tan^{-1}\left[\frac{\mathrm{Im}(H_1(s)H_2(s)H_3(s)H_{RC}(s))}{\mathrm{Re}(H_1(s)H_2(s)H_3(s)H_{RC}(s))}\right]$$

Equation 2.7: Frequency response for a series of Sallen-key LPFs with an additional RC LPF

3. CALIBRATION FILES

3.1 Structure of the Calibration Files

The general structure of the SPIRE LPF parameter calibration files is shown in Table 1.

product (type=" SCalSpecLpfPar|SCalSpecLpfPar", description=Photometer|Spectrometer Low Pass Filter Parameters *class: herschel.spire.ia.dataset.PhotLpfPar|herschel.spire.ia.dataset.SpecLpfPar*						
metadata:						
creator	Creator, String					
creationDate	Creation Date, units=""UTC", Date					
instrument	Instrument, String					
modelName	Instrument Model Name, String					
startDate	Creation Date, units=""UTC", Date					
endDate	Creation Date, units=""UTC", Date					
version	Version, String					
Low Pass Filter Parameters, table dataset						
filter	**r1 [Ω]**	**r2 [Ω]**	**r3 [Ω]**	**r4 [Ω]**	**c1 [Farad]**	**c2 [Farad]**
1						
2						
...						
n						

Table 1: Low Pass Filter Calibration File Structure; applicable to both Photometer and Spectrometer calibration files [AD03].

3.2 Populating the Calibration Files

A set of Low-pass filter calibration files (Photometer and Spectrometer) is required for all iterations of the LPFs of the SPIRE Detector Control Unit readout electronics [**AD01**, **AD02**]. For a given iteration, the individual resistor and capacitor components shown in the Photometer and Spectrometer LPFs circuit diagrams in the SPIRE Detector Control Unit Design Document should be extracted and used to populate the calibration files applicable to that instrument model. In addition, the calibration file metadata should be populated with values appropriate to the Instrument model, the start and end dates between which the calibration file should be applied, as well as the version number for the calibration file.

In the case of the Sallen-key filter components, population of the table dataset is straightforward, with each column having a corresponding resistor or capacitor component. If the LPF chain contains a simple RC LPF component, only the **r1** and **c1** columns should contain non-trivial values while the rest of the entries for that row should be filled with values equal to -1.

4. CALIBRATION FILE CONTENTS

As of the current version of this document, there have been two distinct iterations of the LPFs used in the readout chain for the SPIRE detectors. The first iteration, applicable to the Cryogenic Qualification Model (CQM), is described in [**AD01**]. The second iteration, applicable to the Flight Model (FM), is described in [**AD02**]. The contents of the Photometer and Spectrometer Low-pass filter calibration files for each of these iterations are presented in Sections 4.1.1, 4.1.2, 4.2.1, and 4.2.2.

4.1 CQM Electronics

The filters used in the readout electronics for the CQM model of SPIRE are given in **AD01**.

4.1.1 Photometer

A reproduction of the CQM electronics LPF for the SPIRE Photometer from **AD01** is shown in Figure 4.1.

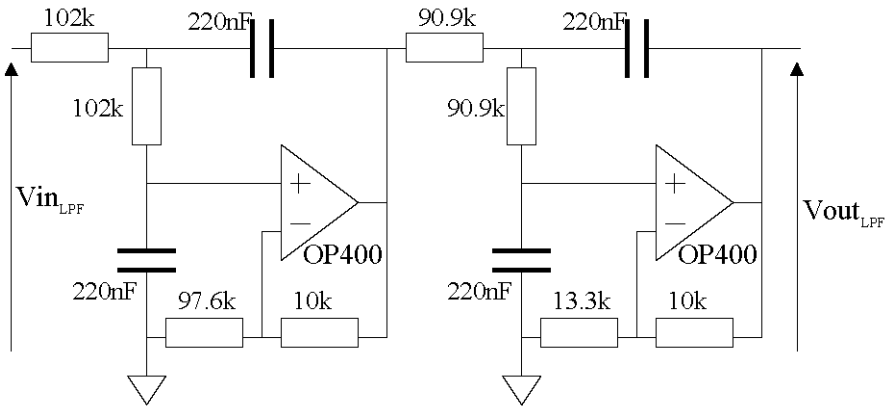

Figure 4.1: SPIRE Photometer LPF, CQM Electronics [AD01]

The corresponding LPF calibration product should therefore contain the following:

product (type="SCalPhotLpfPar", description=Photometer Low Pass Filter Parameters *class: herschel.spire.ia.dataset.PhotLpfPar*						
metadata:						
creator	Creator, String					
creationDate	Creation Date, units='"UTC", Date					
instrument	SPIRE					
modelName	CQM					
startDate	Start Date, units='"UTC", Date					
endDate	End Date, units='"UTC", Date					
version	0					
filter	**r1 [Ω]**	**r2 [Ω]**	**r3 [Ω]**	**r4 [Ω]**	**c1 [Farad]**	**c2 [Farad]**
1	$102x10^3$	$102x10^3$	$97.6x10^3$	$10x10^3$	$220x10^{-9}$	$220x10^{-9}$
2	$90.9x10^3$	$90.9x10^3$	$13.3x10^3$	$10x10^3$	$220x10^{-9}$	$220x10^{-9}$

Table 2: Low Pass Filter Calibration File Contents; SPIRE Photometer, CQM edition

The transfer function for the Photometer LPF shown in Figure 4.1 can be derived by inserting the component values into Equation 2.6 and is given in Equation 4.1: CQM Photometer LPF transfer function:

$$H(s) = 1.93 \times \frac{1}{1 + 42.58 \times 10^{-3} s + 503 \times 10^{-6} s^2} \times \frac{1}{1 + 24.96 \times 10^{-3} s + 399 \times 10^{-6} s^2}$$

Equation 4.1: CQM Photometer LPF transfer function

The transfer function for the Photometer LPF given in **AD01** is shown in Equation 4.2

$$H(s) = 1.93 \times \frac{1}{1 + 42.58 s + 503 s^2} \times \frac{1}{1 + 24.96 s + 399 s^2}$$

Equation 4.2: CQM Photometer LPF transfer function [AD01]

The transfer functions shown in Equation 4.1 and Equation 4.2 agree in terms of the overall gain, but their denominators are quite different. By way of further comparison, refer to the magnitude response curves derived from Equation 4.1 and Equation 4.2 (Figure 4.2) and the magnitude response curve from **AD01** (Figure 4.3).

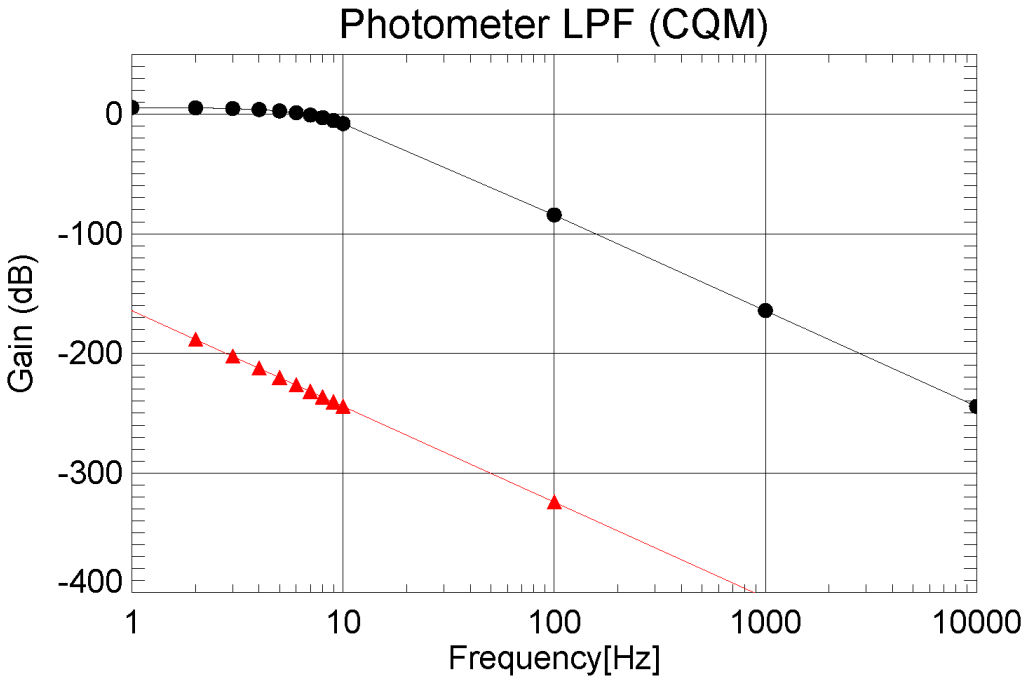

Figure 4.2: Photometer LPF magnitude response. The black curve is derived from Equation 4.1; the red curve is derived from Equation 4.2.

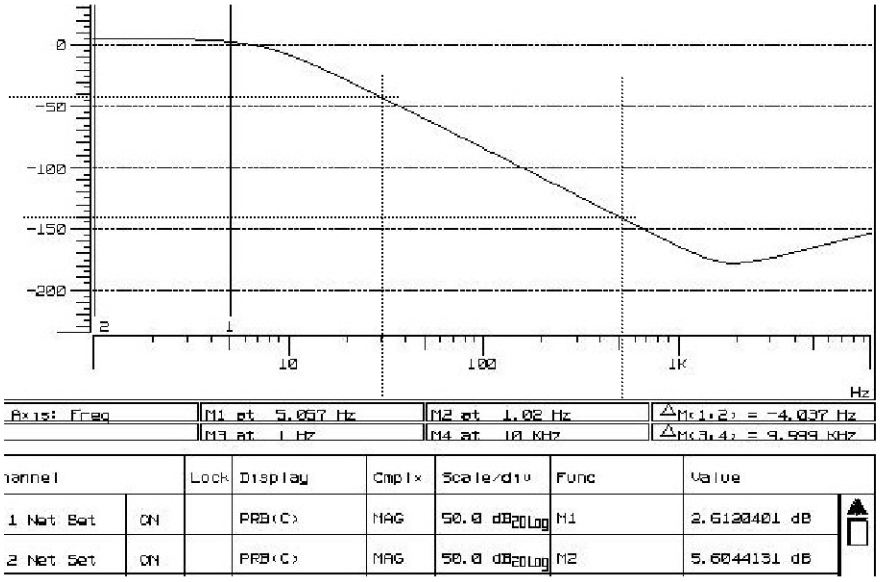

Figure 4.3: LIA Photometer LPF Magnitude Transfer Function [AD01]

As can be seen from the comparison between the curves in Figure 4.2 and Figure 4.3, the magnitude curve produced from the transfer function derived from the filter components most closely matches that from **AD01**. As such, the transfer function derived from the filter components will be taken as correct.

4.1.2 Spectrometer

A reproduction of the CQM electronics LPF for the SPIRE Spectrometer from **AD01** is shown in Figure 4.4.

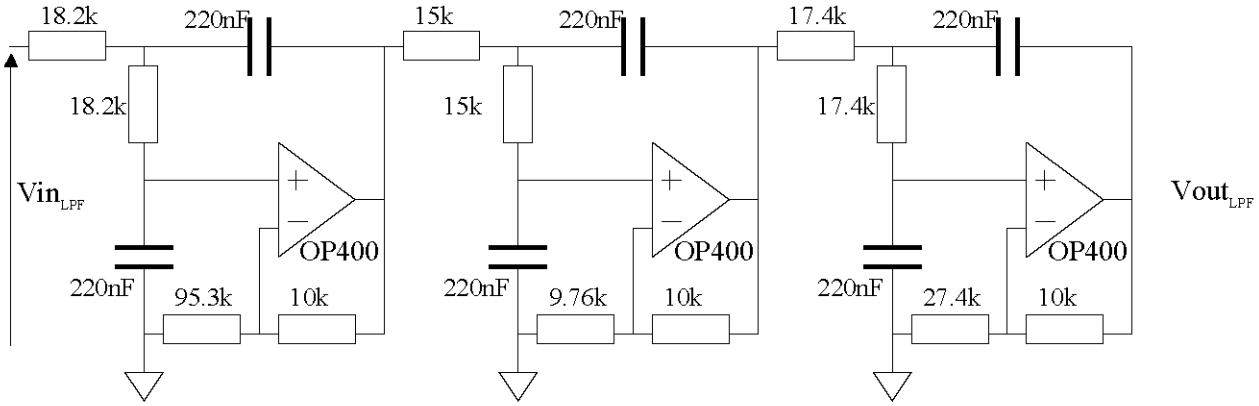

Figure 4.4: SPIRE Spectrometer LPF, CQM Electronics [AD01]

The corresponding LPF calibration product should therefore contain the following:

product (type="SCalSpecLpfPar", description= Spectrometer Low Pass Filter Parameters class: herschel.spire.ia.dataset.SpecLpfPar	
metadata:	
creator	Creator, String
creationDate	Creation Date, units='"UTC", Date
instrument	SPIRE
modelName	CQM
startDate	Start Date, units='"UTC", Date

endDate			End Date, units=’”UTC”, Date			
version			0			
filter	**r1 [Ω]**	**r2 [Ω]**	**r3 [Ω]**	**r4 [Ω]**	**c1 [Farad]**	**c2 [Farad]**
1	$18.2\text{x}10^{3}$	$18.2\text{x}10^{3}$	$95.3\text{x}10^{3}$	$10\text{x}10^{3}$	$220\text{x}10^{-9}$	$220\text{x}10^{-9}$
2	$15\text{x}10^{3}$	$15\text{x}10^{3}$	$9.76\text{x}10^{3}$	$10\text{x}10^{3}$	$220\text{x}10^{-9}$	$220\text{x}10^{-9}$
3	$17.4\text{x}10^{3}$	$17.4\text{x}10^{3}$	$27.4\text{x}10^{3}$	$10\text{x}10^{3}$	$220\text{x}10^{-9}$	$220\text{x}10^{-9}$

Table 3: Low Pass Filter Calibration File Contents; SPIRE Spectrometer, CQM edition

The transfer function for the Spectrometer LPF shown in Figure 4.4 can be derived by inserting the component values into Equation 2.6 and is given in Equation 4.3:

$$H(s) = 3.05 \times \frac{1}{1 + 7.59\times10^{-3}s + 16\times10^{-6}s^2} \times \frac{1}{1 + 3.22\times10^{-3}s + 10.9\times10^{-6}s^2} \times \frac{1}{1 + 6.26\times10^{-3}s + 14.65\times10^{-6}s^2}$$

Equation 4.3: CQM Spectrometer LPF transfer function

The transfer function for the Spectrometer LPF given in **AD01** is shown in Equation 4.4

$$H(s) = 3.05 \times \frac{1}{1 + 7.58s + 4s^2} \times \frac{1}{1 + 3.21s + 3.3s^2} \times \frac{1}{1 + 6.26s + 3.828s^2}$$

Equation 4.4: CQM Spectrometer LPF transfer function [AD01]

The transfer functions shown in Equation 4.3 and Equation 4.4 agree in terms of the overall gain, but their denominators are quite different. By way of further comparison, refer to the magnitude response curves derived from Equation 4.3 and Equation 4.4 (Figure 4.5) and the magnitude response curve from **AD01** (Figure 4.6).

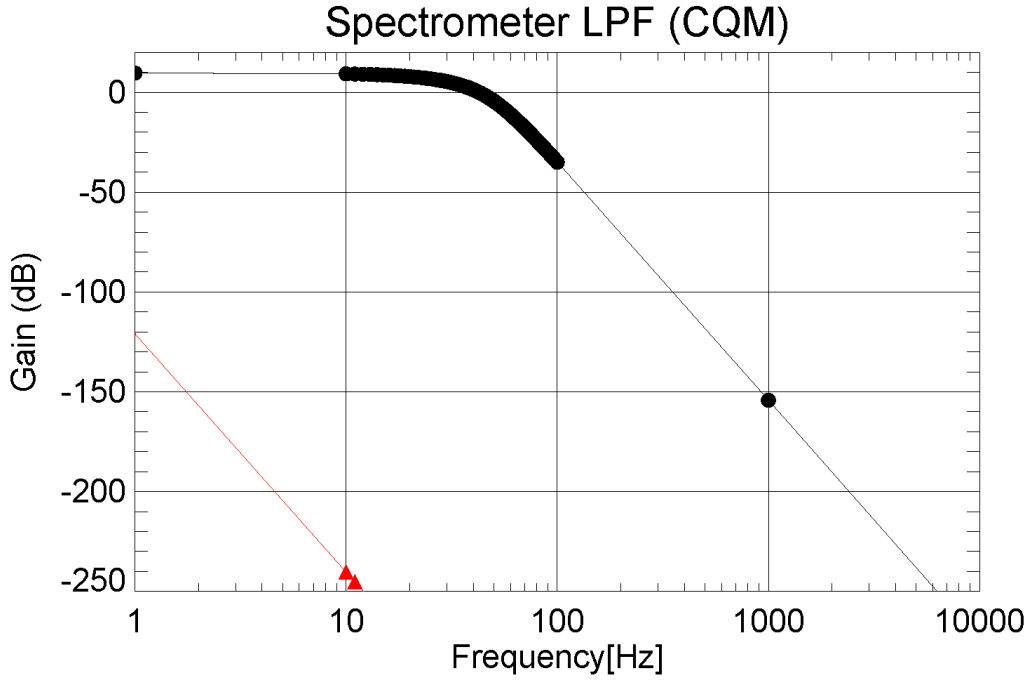

Figure 4.5: Spectrometer LPF magnitude response. The black curve is derived from Equation 4.3; the red curve is derived from Equation 4.4.

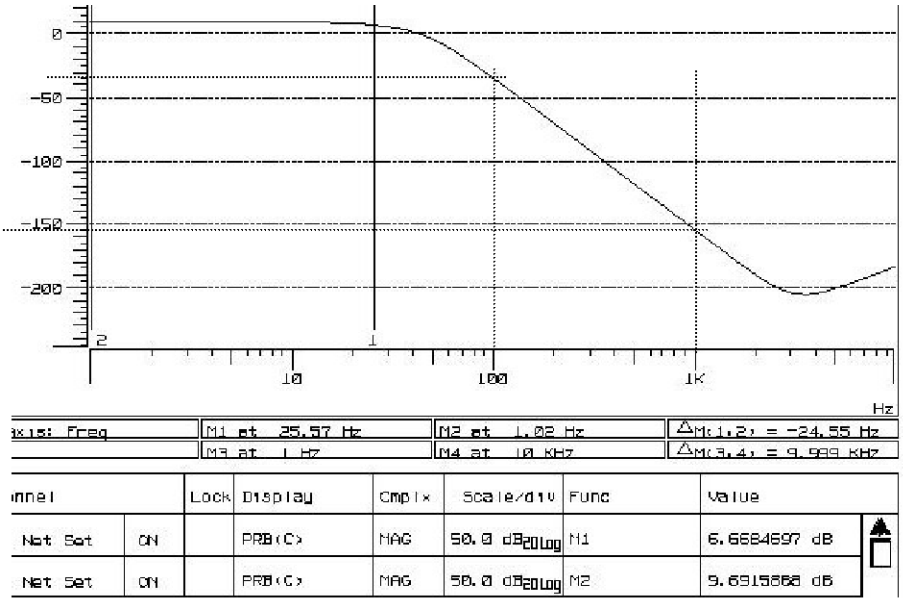

Figure 4.6: LIA Spectrometer LPF Magnitude Transfer Function [AD01]

As can be seen from the comparison between the curves in Figure 4.5 and Figure 4.6, the magnitude curve produced from the transfer function derived from the filter components most closely matches that from **AD01**. As such, the transfer function derived from the filter components will be taken as correct

4.2 FM Electronics

The filters used in the readout electronics for the FM model of SPIRE are given in **AD02**.

4.2.1 Photometer

A reproduction of the FM electronics LPF for the SPIRE Photometer from **AD02** is shown in Figure 4.7.

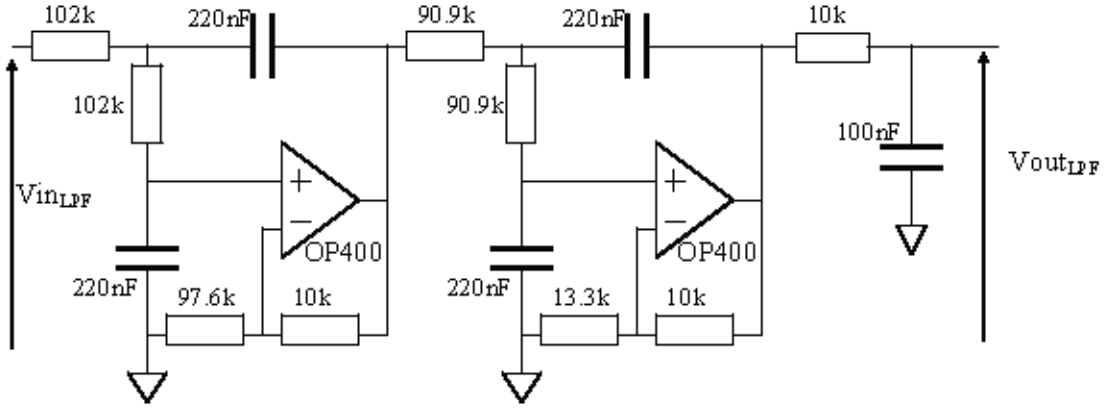

Figure 4.7: SPIRE Photometer LPF, CQM Electronics [AD02]

The corresponding LPF calibration product should therefore contain the following:

product (type="SCalPhotLpfPar", description=Photometer Low Pass Filter Parameters
class: herschel.spire.ia.dataset.PhotLpfPar

metadata:	
creator	Creator, String
creationDate	Creation Date, units='"UTC", Date
instrument	SPIRE
modelName	FM
startDate	Start Date, units='"UTC", Date
endDate	End Date, units='"UTC", Date
version	0

filter	r1 [Ω]	r2 [Ω]	r3 [Ω]	r4 [Ω]	c1 [Farad]	c2 [Farad]
1	102×10^{3}	102×10^{3}	97.6×10^{3}	10×10^{3}	220×10^{-9}	220×10^{-9}
2	90.9×10^{3}	90.9×10^{3}	13.3×10^{3}	10×10^{3}	220×10^{-9}	220×10^{-9}
3	10×10^{3}	-1	-1	-1	100×10^{-9}	-1

Table 4: Low Pass Filter Calibration File Contents; SPIRE Photometer, FM edition

The transfer function for the Photometer LPF shown in Figure 4.7 can be derived by inserting the component values into Equation 2.6 and is given in Equation 4.5:

$$H(s)=1.93\times\frac{1}{1+42.58\times10^{-3}s+503\times10^{-6}s^{2}}\times\frac{1}{1+24.96\times10^{-3}s+399\times10^{-6}s^{2}}\times\frac{1}{1+10^{-3}s}$$

Equation 4.5: FM Photometer LPF transfer function

The transfer function for the Photometer LPF given in **AD02** is shown in Equation 4.6

$$H(s)=1.93\times\frac{1}{1+42.58\times10^{-3}s+503\times10^{-6}s^{2}}\times\frac{1}{1+24.96\times10^{-3}s+399\times10^{-6}s^{2}}\times\frac{1}{1+10^{-3}s}$$

Equation 4.6: FM Photometer LPF transfer function

Not only do the transfer functions shown in Equation 4.5 and Equation 4.6 agree, but the magnitude response curves derived from these equations also agree (see Figure 4.8, Figure 4.9).

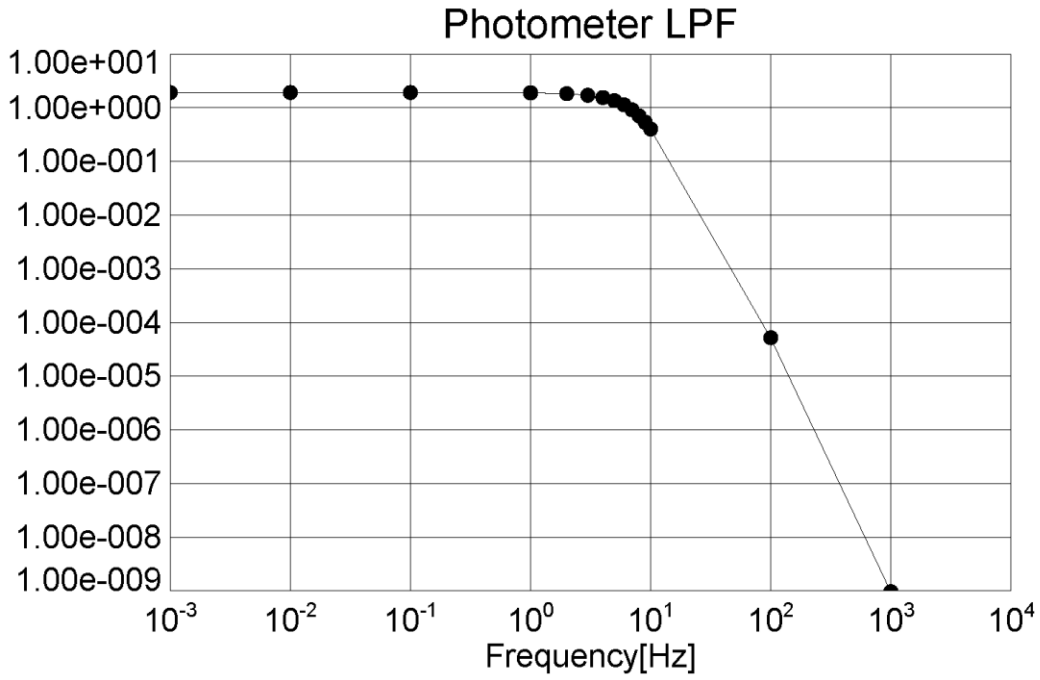

Figure 4.8: Photometer LPF magnitude response derived from component values

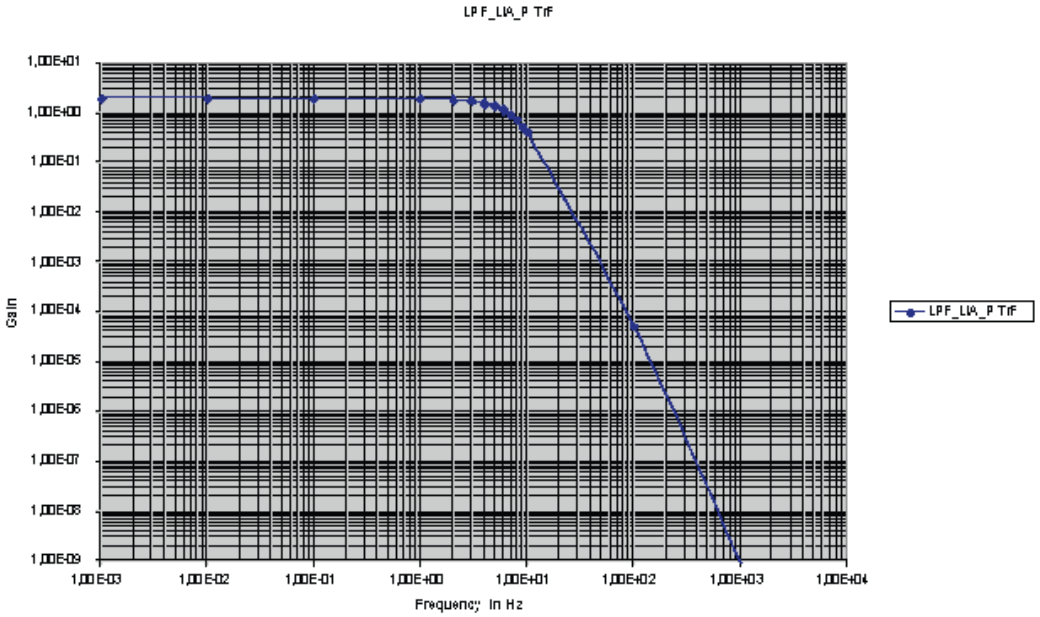

Figure 4.9: LIA Photometer LPF Magnitude Transfer Function [AD02]

4.2.2 Spectrometer

A reproduction of the FM electronics LPF for the SPIRE Spectrometer from **AD02** is shown in Figure 4.10.

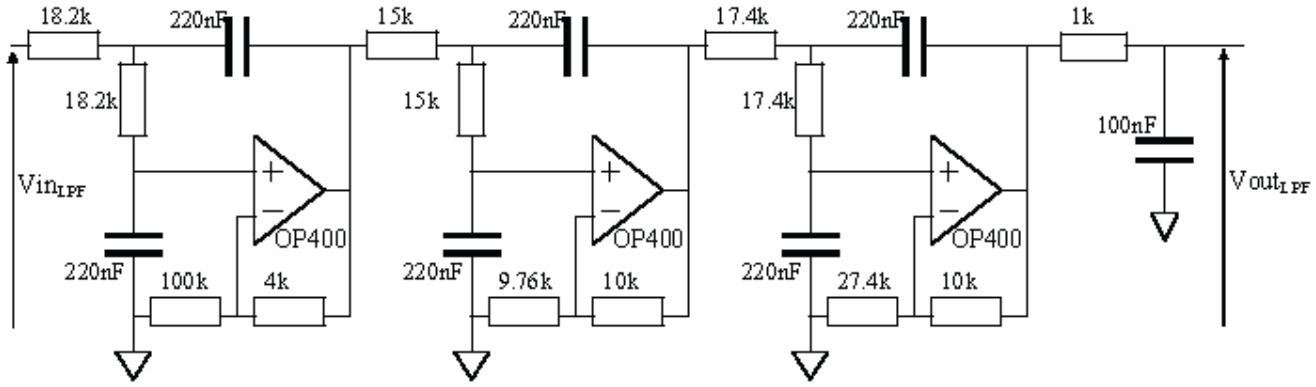

Figure 4.10: SPIRE Spectrometer LPF, FM Electronics [AD02]

The corresponding LPF calibration product should therefore contain the following:

product (type="SCalSpecLpfPar", description= Spectrometer Low Pass Filter Parameters class: herschel.spire.ia.dataset.SpecLpfPar	
metadata:	
creator	Creator, String
creationDate	Creation Date, units='"UTC", Date
instrument	SPIRE
modelName	FM
startDate	Start Date, units='"UTC", Date
endDate	End Date, units='"UTC", Date

version			0			
filter	r1 [Ω]	r2 [Ω]	r3 [Ω]	r4 [Ω]	c1 [Farad]	c2 [Farad]
1	$18.2\text{x}10^3$	$18.2\text{x}10^3$	$100\text{x}10^3$	$4\text{x}10^3$	$220\text{x}10^{-9}$	$220\text{x}10^{-9}$
2	$15\text{x}10^3$	$15\text{x}10^3$	$9.76\text{x}10^3$	$10\text{x}10^3$	$220\text{x}10^{-9}$	$220\text{x}10^{-9}$
3	$17.4\text{x}10^3$	$17.4\text{x}10^3$	$27.4\text{x}10^3$	$10\text{x}10^3$	$220\text{x}10^{-9}$	$220\text{x}10^{-9}$
4	$1\text{x}10^3$	-1	-1	-1	$100\text{x}10^{-9}$	-1

Table 5: Low Pass Filter Calibration File Contents; SPIRE Spectrometer, FM edition

The transfer function for the Spectrometer LPF shown in Figure 4.10 can be derived by inserting the component values into Equation 2.6 and is given in Equation 4.7:

$$H(s) = 2.87 \times \frac{1}{1+7.85\times10^{-3}s+16\times10^{-6}s^2} \times \frac{1}{1+3.22\times10^{-3}s+10.9\times10^{-6}s^2} \times \frac{1}{1+6.26\times10^{-3}s+14.65\times10^{-6}s^2} \times \frac{1}{1+10^{-4}s}$$

Equation 4.7: FM Spectrometer LPF transfer function

Note: There is a slight difference between the transfer function shown in Equation 4.7 and that presented in 3.6.3.4.2 of **AD02**. The latter is reproduced in

$$H(s) = 2.86 \times \frac{1}{1+7.85\times10^{-3}s+16\times10^{-6}s^2} \times \frac{1}{1+3.25\times10^{-3}s+10.9\times10^{-6}s^2} \times \frac{1}{1+6.26\times10^{-3}s+14.65\times10^{-6}s^2} \times \frac{1}{1+10^{-4}s}$$

Equation 4.8: FM Spectrometer LPF transfer function from AD02

The magnitude response curves produced from the transfer function shown in Equation 4.7 and that shown directly in **AD02** are shown in Figure 4.11 and Figure 4.12, respectively.

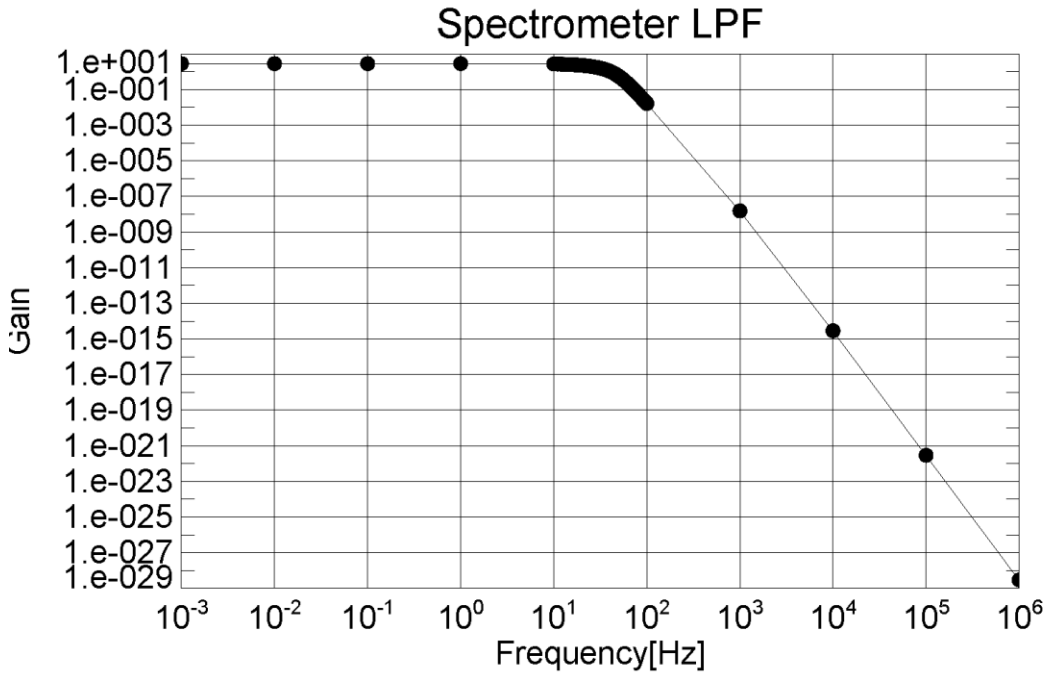

Figure 4.11: Spectrometer LPF magnitude response derived from component values

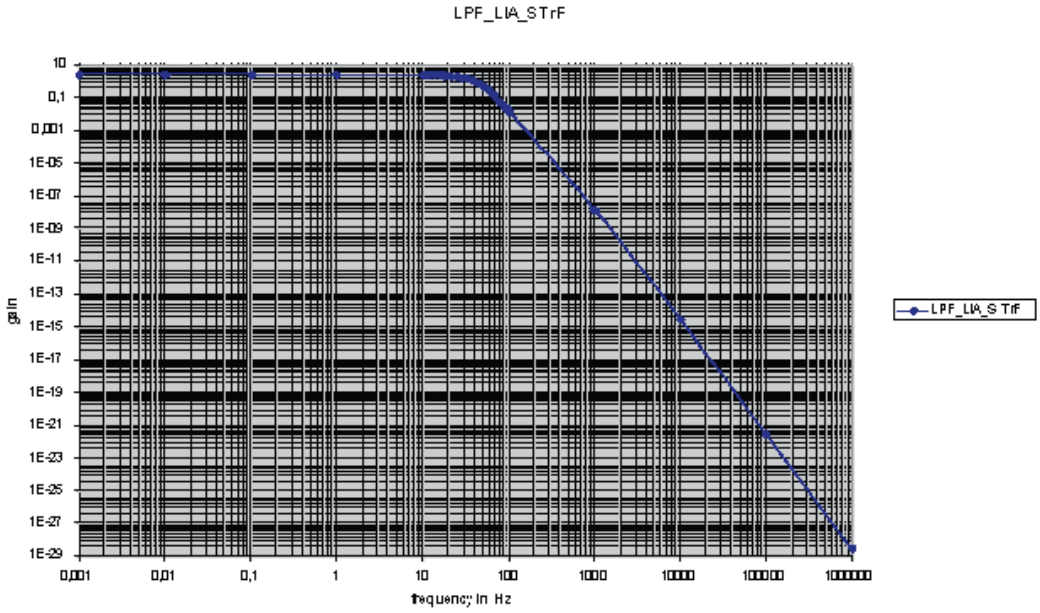

Figure 4.12: LIA Spectrometer LPF Magnitude Transfer Function [AD02]

While the differences between the transfer function derived from the low-pass filter components and the transfer function presented in the DCU Design document are not as great for the FM version as they were for the CQM version (see §4.1.2), there are nonetheless still differences. As such, the transfer function derived from the components (Equation 4.7) will be taken as correct.